Manipulation of circular polarised electromagnetic waves by artificial periodic structures (Invited Paper)

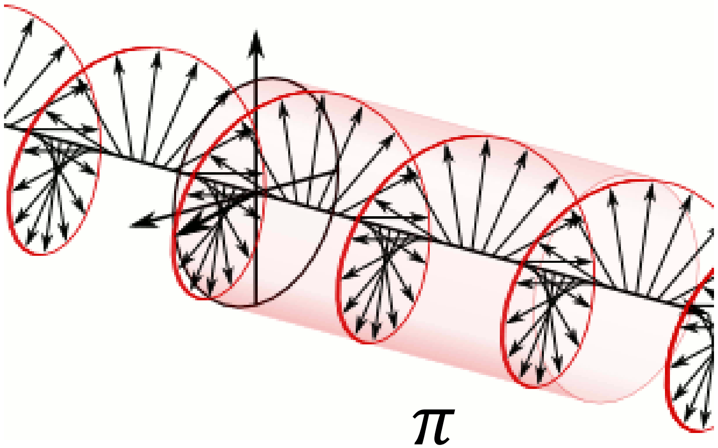
Manipulation of circular polarised electromagnetic waves by artificial periodic structures

D. Zelenchuk, and V. Fusco

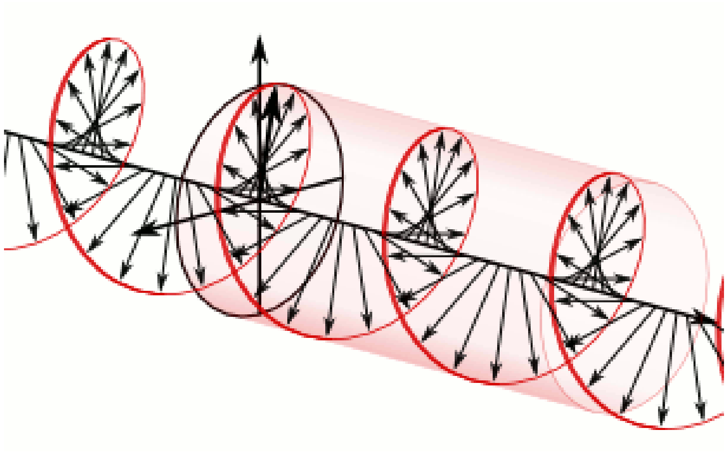
December 8, 2015

Circularly polarised wave

RHCP wave



$$|E_x| = |E_y| \qquad \varphi_y - \varphi_x = \pm\frac{\pi}{2}$$



LHCP wave

The hand is defined from the point of view of the source

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Outline

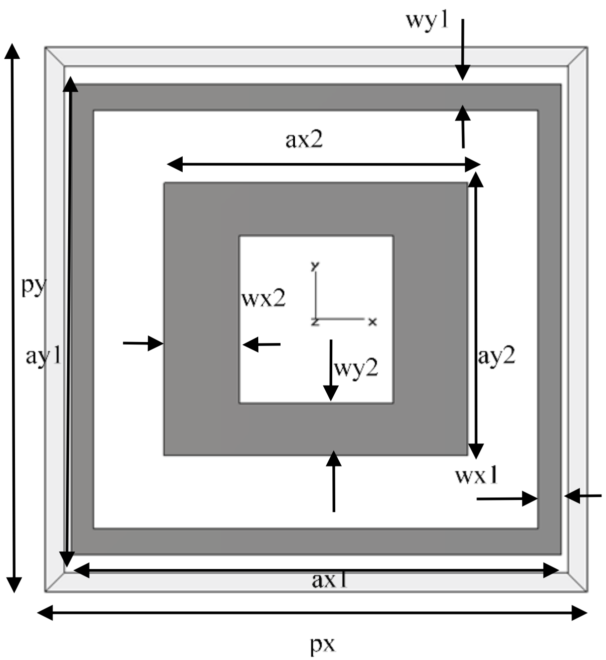
- Spectral selectivity: CP frequency selective surfaces
- Beam forming: Conical beam generation with rotational phase shift
- Polarisation selectivity: circularly polarised selective surface (CPSS)

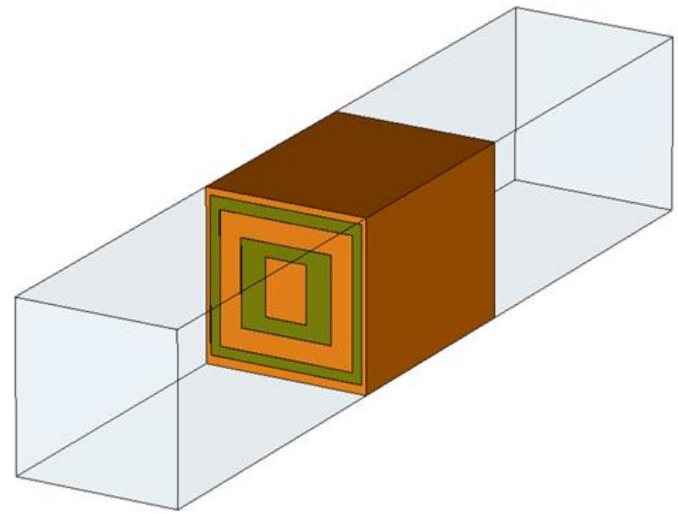
Motivation

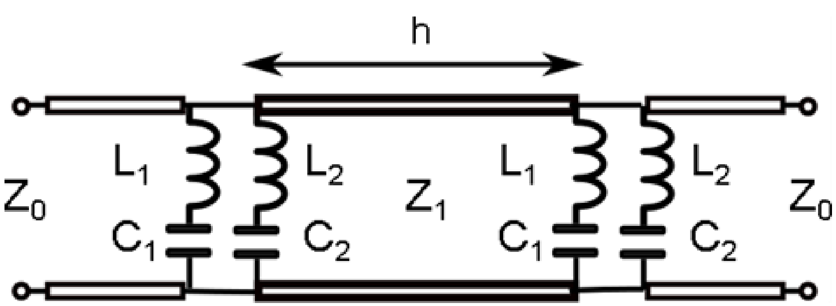
- Frequency selective surfaces (FSS) remain a key component of satellite antenna feeding sub-systems
- They provide low-loss filtering and beam-splitting capacity that allows using single antenna for multi-band operation
- FSS is dual-polarisation or even circular polarisation (CP) properties
- Properties of the dielectric stack utilised to support printed FSS structure becomes crucial for successful design

	Ku-band	**Ka-band**
Frequencies (GHz)	11.7-12.75	17.3-20.2
Losses (dB)	Reflected <0.25dB	Transmitted <0.25dB
Rejection (dB)	30 dB	N/A
Axial Ratio (dB)	0.25	0.25

45 degree angle of incidence!







$$\Gamma_i = -\frac{1}{1 + 2Z_c/Z_0}$$

$$\Gamma_c^{TE} = \Gamma_c^{TM}$$

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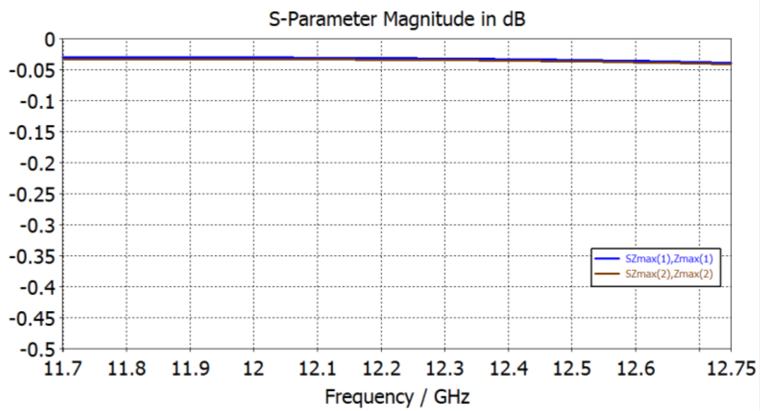
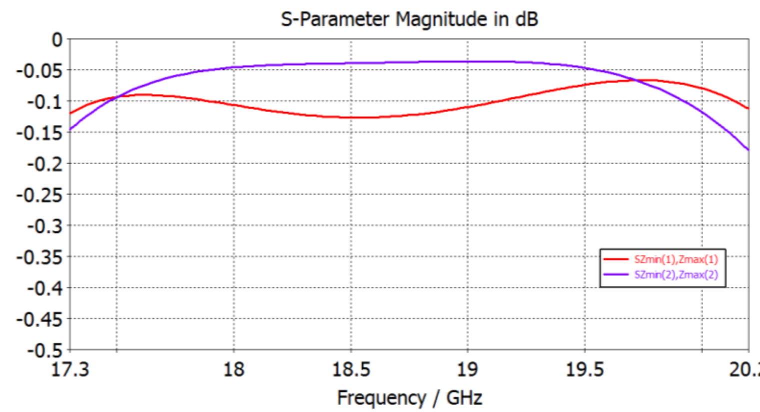
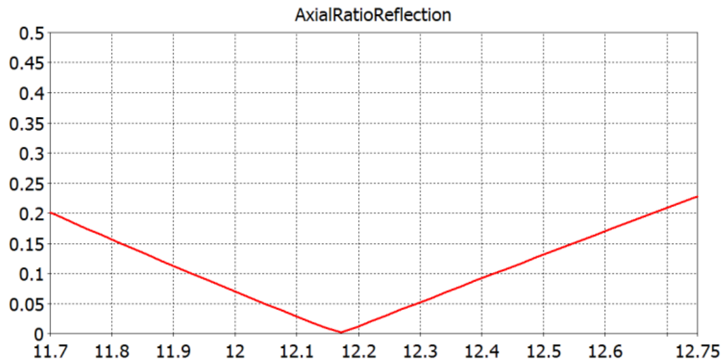
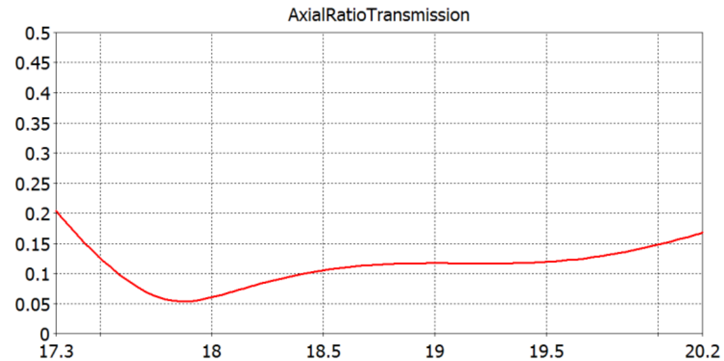
Ku-band Reflection

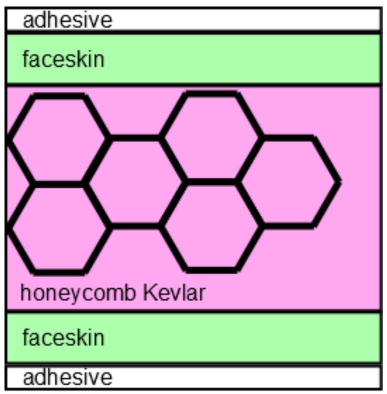


Ka-band Transmission

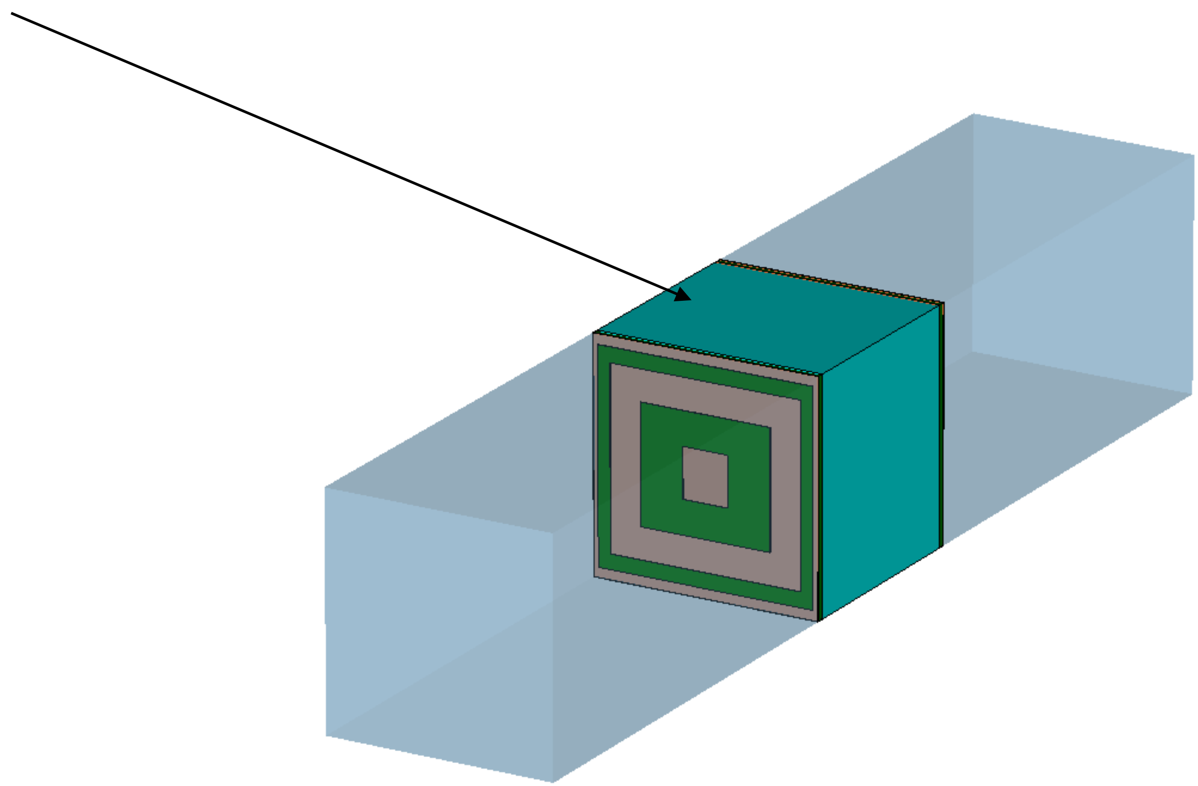


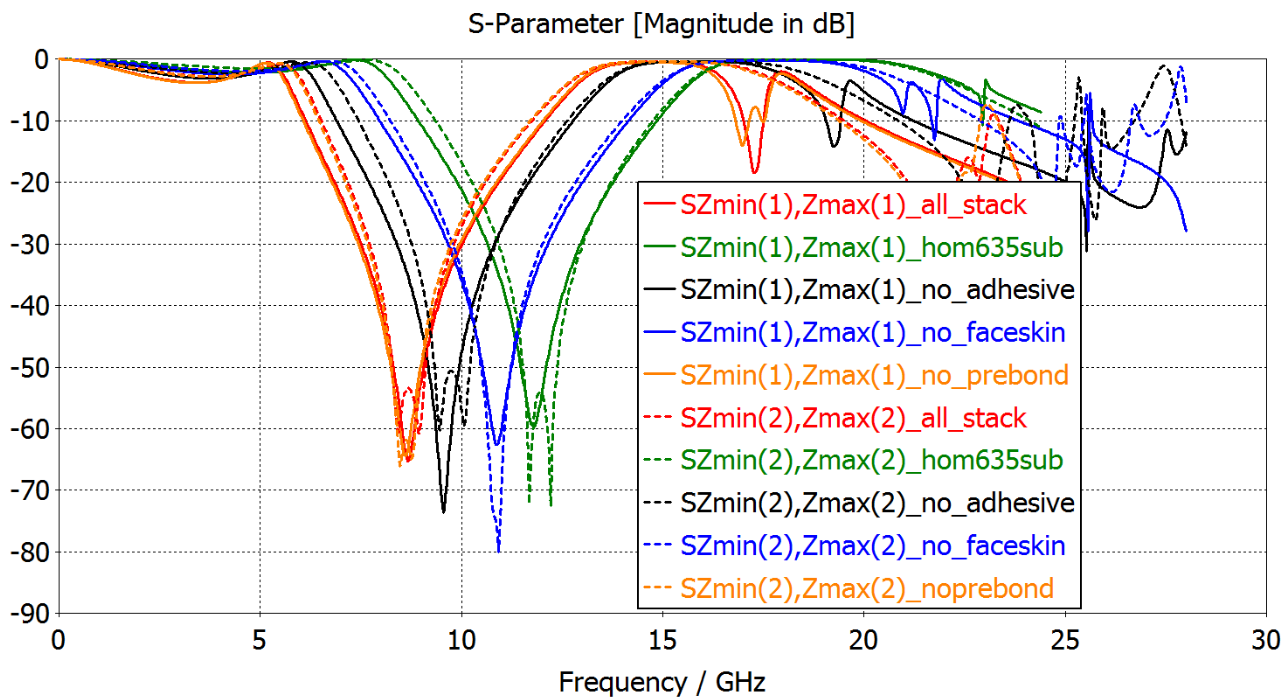


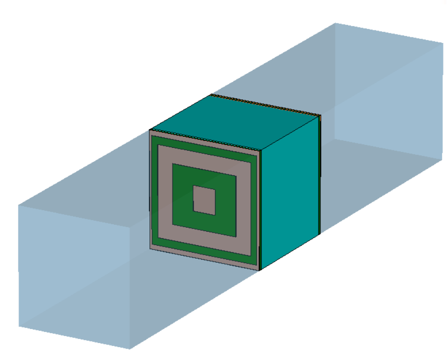


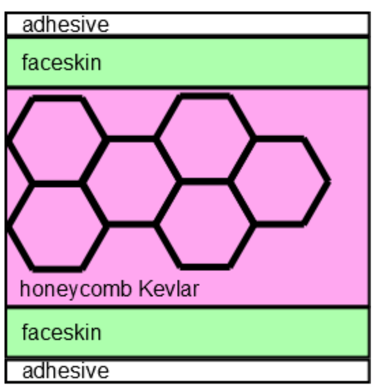


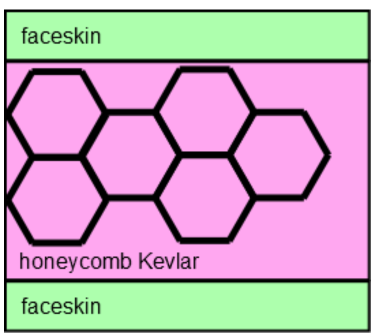
Material stack inside the structure

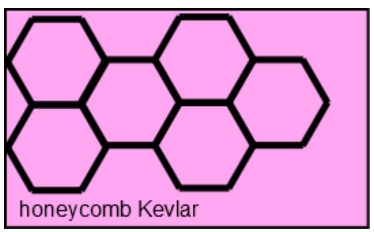


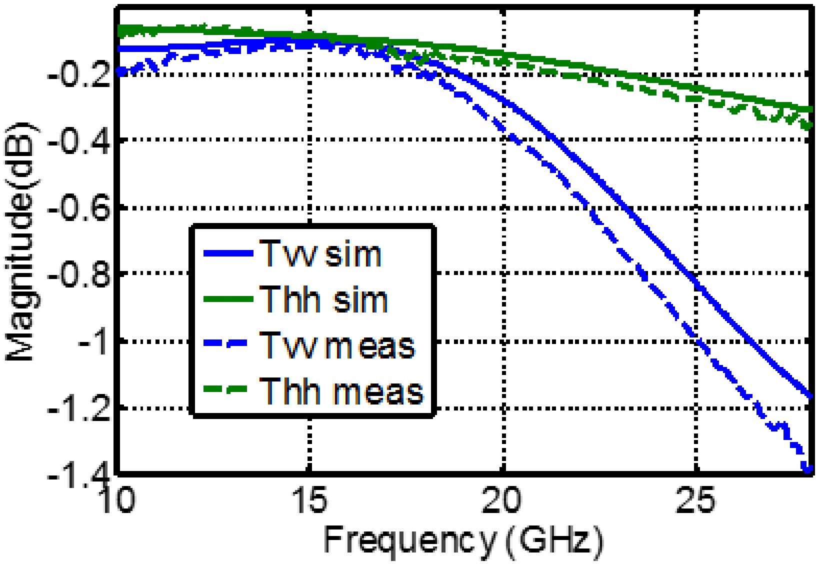

S-Parameter [Magnitude in dB]
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
5
10
15
20
25
30
Frequency / GHz
SZmin(1),Zmax(1)_all_stack
SZmin(1),Zmax(1)_hom635sub
SZmin(1),Zmax(1)_no_adhesive
SZmin(1),Zmax(1)_no_faceskin
SZmin(1),Zmax(1)_no_prebond
SZmin(2),Zmax(2)_all_stack
SZmin(2),Zmax(2)_hom635sub
SZmin(2),Zmax(2)_no_adhesive
SZmin(2),Zmax(2)_no_faceskin
SZmin(2),Zmax(2)_noprebond

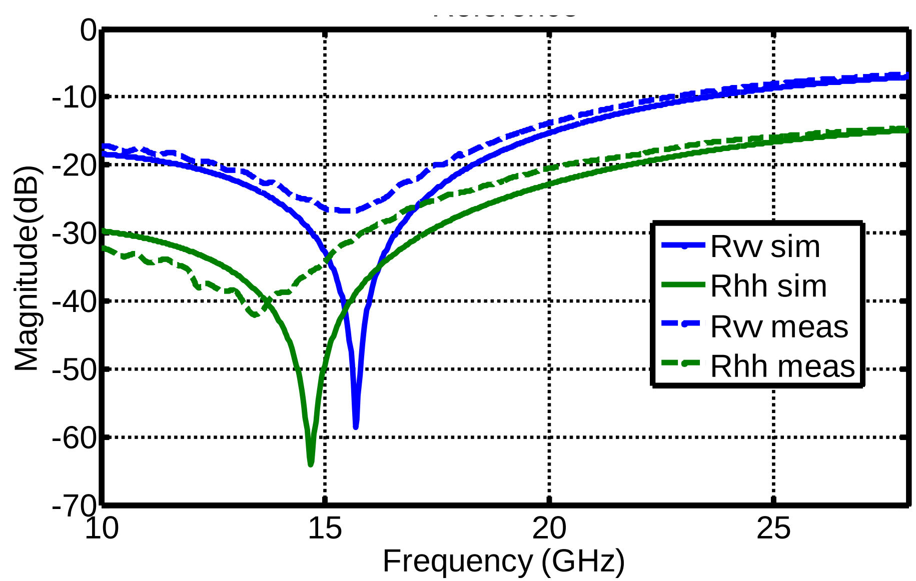



adhesive
faceskin
honeycomb Kevlar
faceskin
adhesive

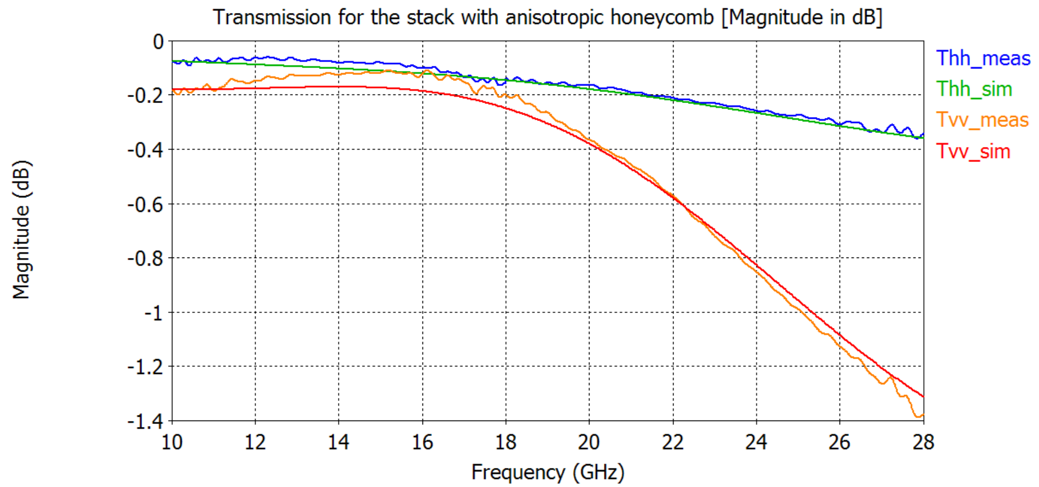

faceskin
honeycomb Kevlar
faceskin


honeycomb Kevlar

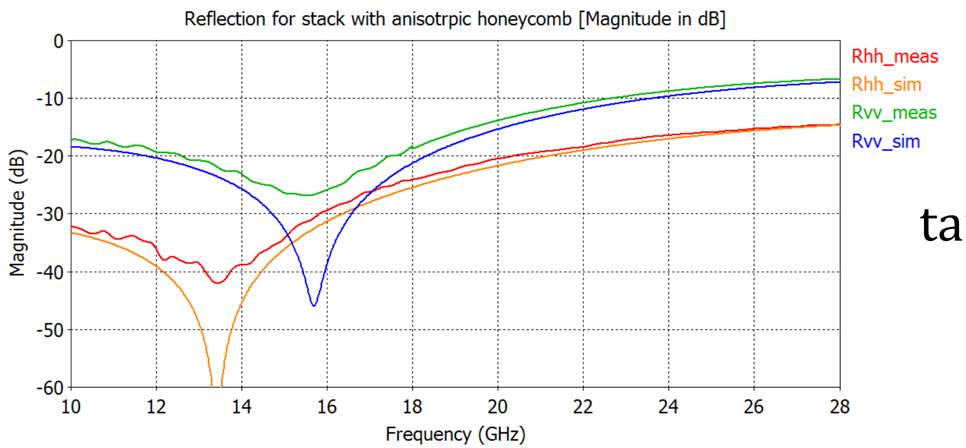




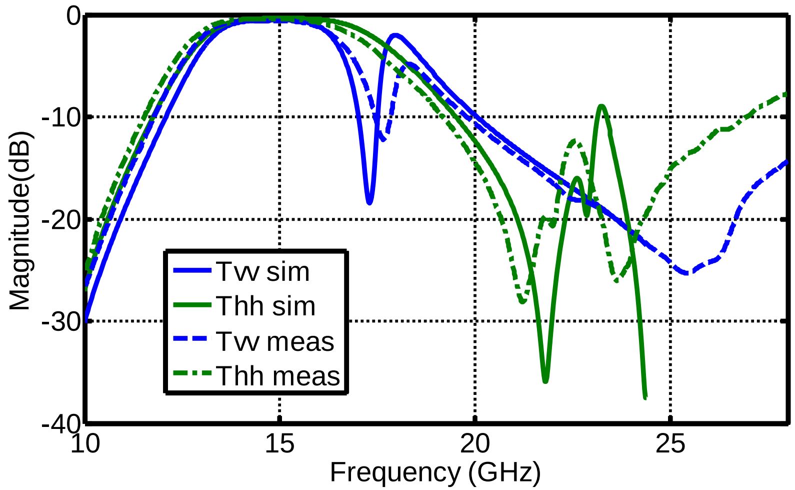
There is a notable difference between the measured results and simulation of the material stack

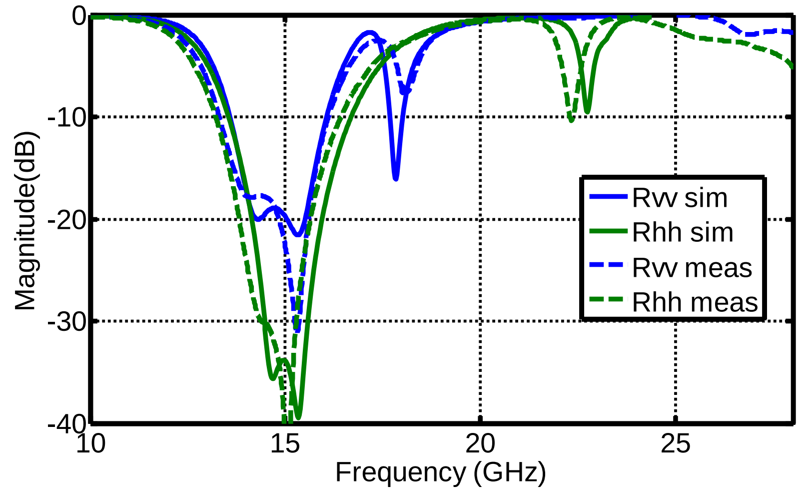


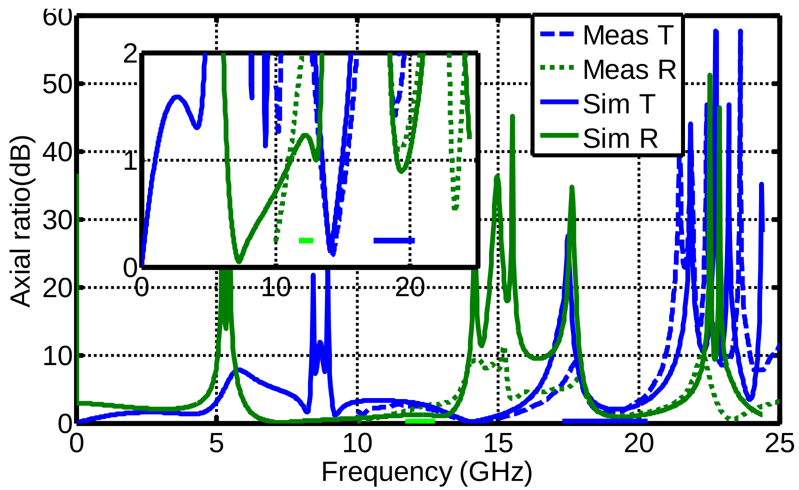
$$\varepsilon_r = \begin{pmatrix} 1.02 & 0 & 0 \\ 0 & 1.05 & 0 \\ 0 & 0 & 1.05 \end{pmatrix}$$

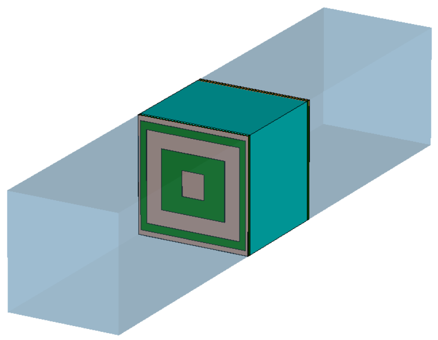


$$\tan\delta = \begin{pmatrix} 0.007 & 0 & 0 \\ 0 & 0.012 & 0 \\ 0 & 0 & 0.007 \end{pmatrix}$$


Magnitude(dB)
Frequency (GHz)
Tvv sim
Thh sim
Tvv meas
Thh meas


Magnitude(dB)
Frequency (GHz)
Rvv sim
Rhh sim
Rvv meas
Rhh meas


Axial ratio(dB)
Frequency (GHz)
Meas T
Meas R
Sim T
Sim R



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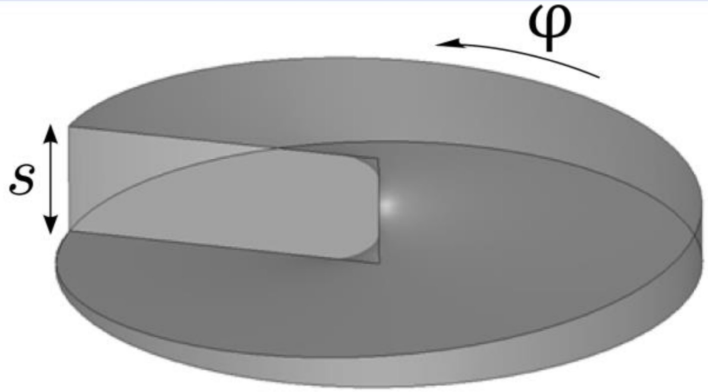
Conical beam applications

- Conical beam antennas have omnidirectional radiation pattern in azimuth and a notch in the normal direction
- “Exotic” applications :
  - Data transfer by free-space modes with non-zero orbital angular momentum
  - Vortex coronography, where object is in the “shadow” of much brighter one

Conical beam generation

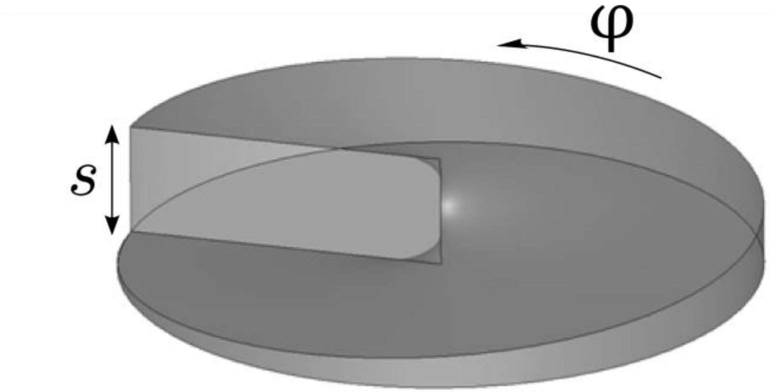


spiral phase plate

helicoidal dish

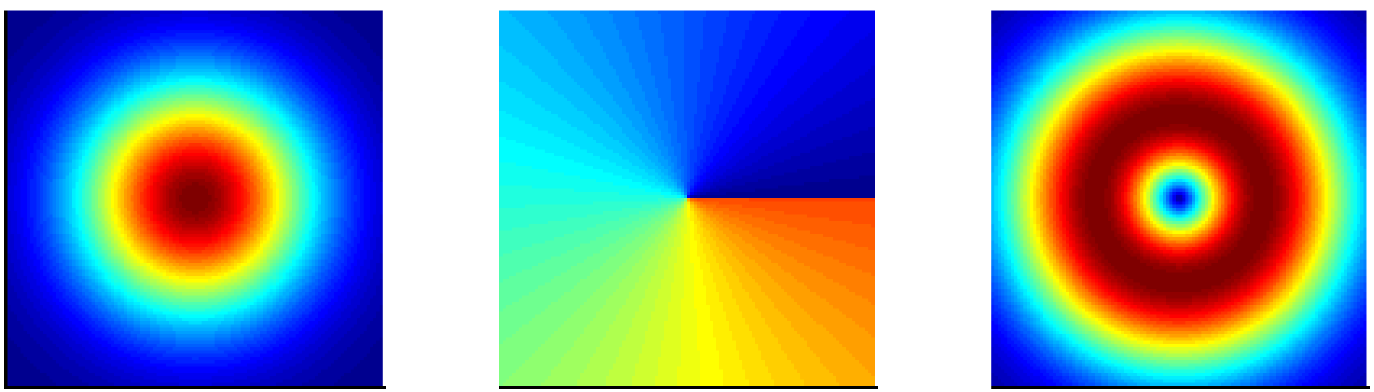
sectorial spiral reflector

ECIT | Spiral phase plate



$$\psi = \frac{\left(\sqrt{\varepsilon} - 1\right) s}{\lambda} \varphi$$

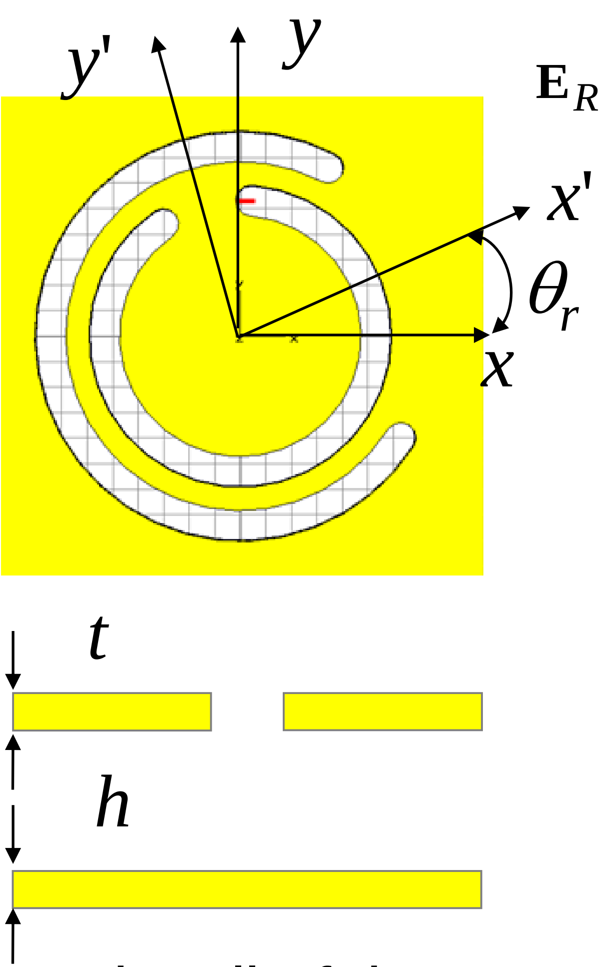
$$s = \frac{l\lambda}{\sqrt{\varepsilon} - 1} \quad for\ \psi = 2\pi l, l \in \mathrm{N}$$



(a) (b) (c)

Generation of helical beam: (a) amplitude of incident Gaussian beam, (b) spiral phase plate, (c) amplitude of resultant Laguerre-Gaussian beam.

Rotational phase shift



Unit cell of the reflecting FSS

$$\mathbf{E}_R = \begin{pmatrix} \cos\theta_r & -\sin\theta_r \\ \sin\theta_r & \cos\theta_r \end{pmatrix} \begin{pmatrix} \Gamma_{x'} & 0 \\ 0 & \Gamma_{y'} \end{pmatrix} \begin{pmatrix} \cos\theta_r & \sin\theta_r \\ -\sin\theta_r & \cos\theta_r \end{pmatrix} \mathbf{E}_i$$

$$\Gamma_{x'} = -\Gamma_{y'}$$

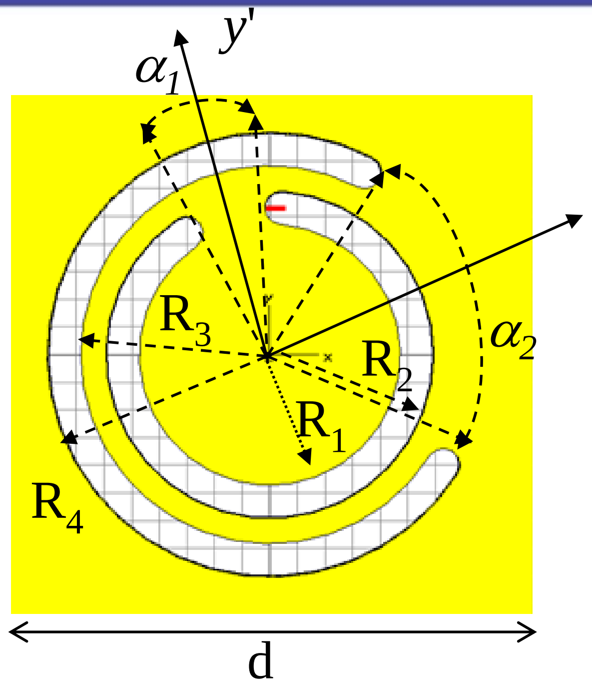
Half-wave plate condition

$$\mathbf{E}_i = \frac{1}{2}\begin{pmatrix} 1 \\ \pm j \end{pmatrix} e^{-jkz}$$

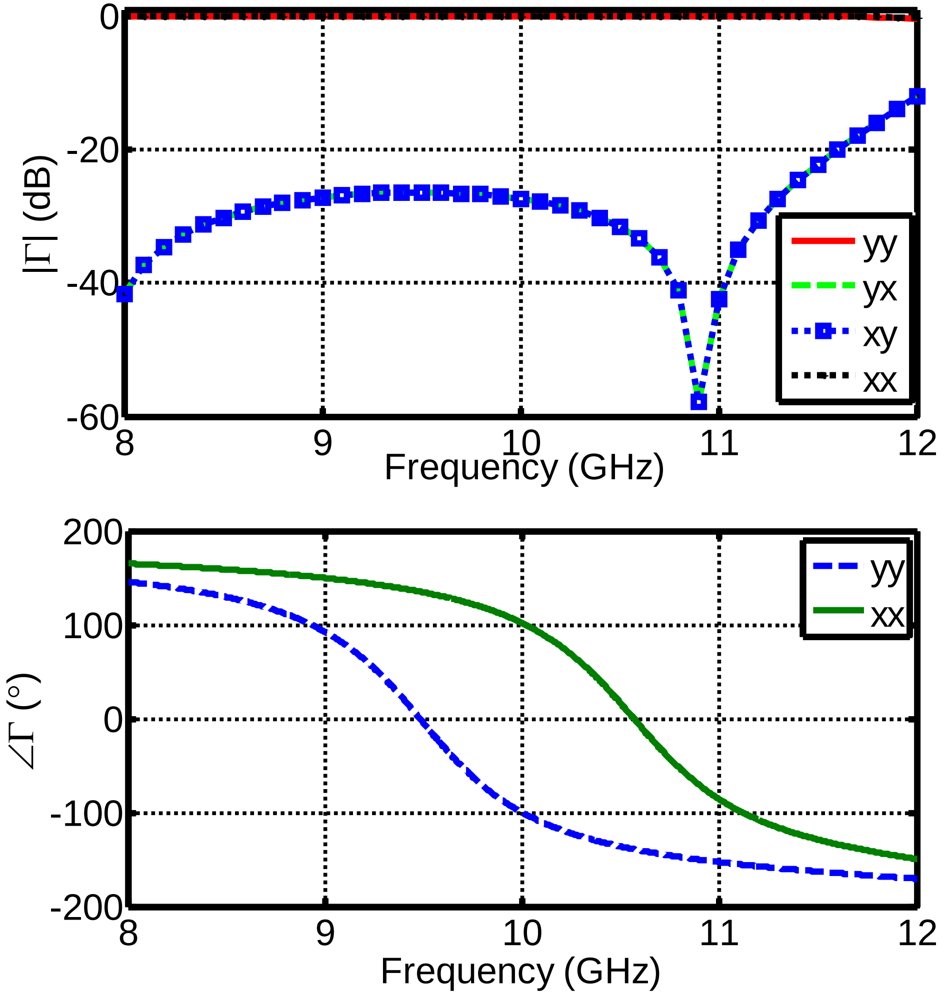
CP excitation

$$\mathbf{E}_R = \Gamma_{x'} e^{\pm j 2\theta_r} \frac{1}{2}\begin{pmatrix} 1 \\ \mp j \end{pmatrix} e^{jkz}$$

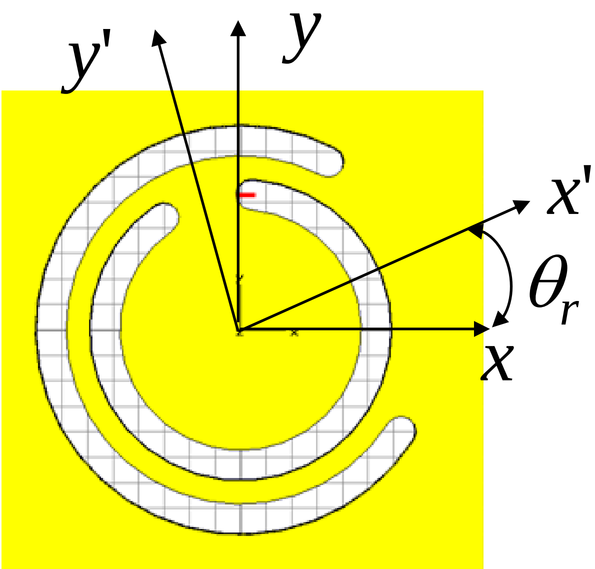
LP analysis of reflecting FSS



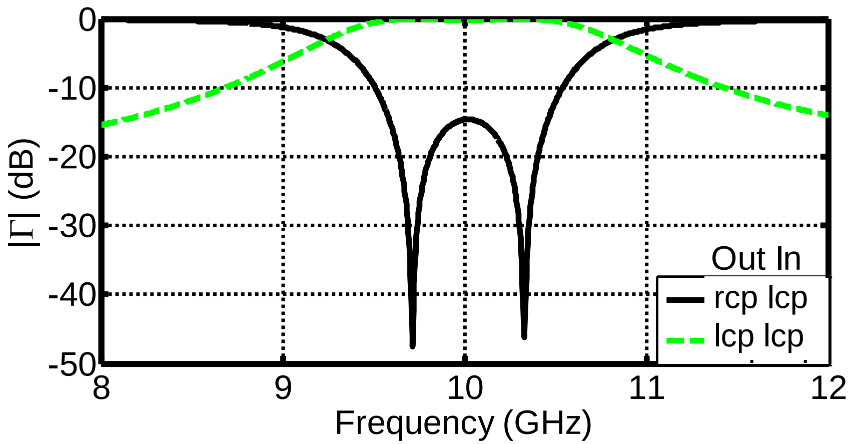
R_1,mm	R_2,mm	R_3,mm	R_4,mm
4.7	5.9	6.8	8
α_1, deg	α_2, deg	h, mm	d, mm
21	95	7.5	19

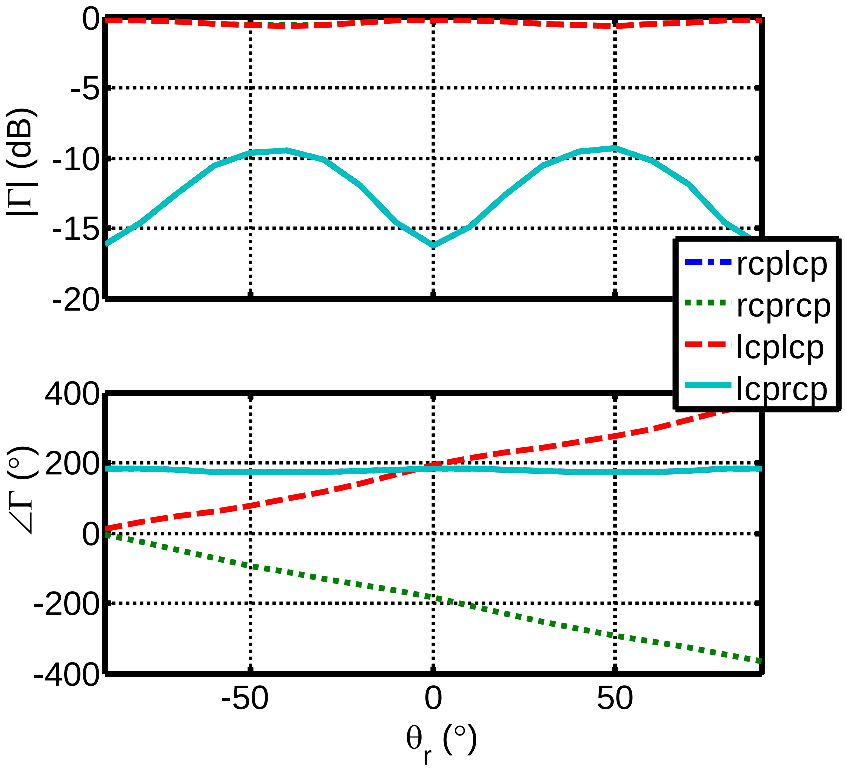


CP analysis of reflecting FSS



$$\mathbf{E}_R = \Gamma_{x'} e^{\pm j 2\theta_r} \frac{1}{2}\begin{pmatrix} 1 \\ \mp j \end{pmatrix} e^{jkz}$$

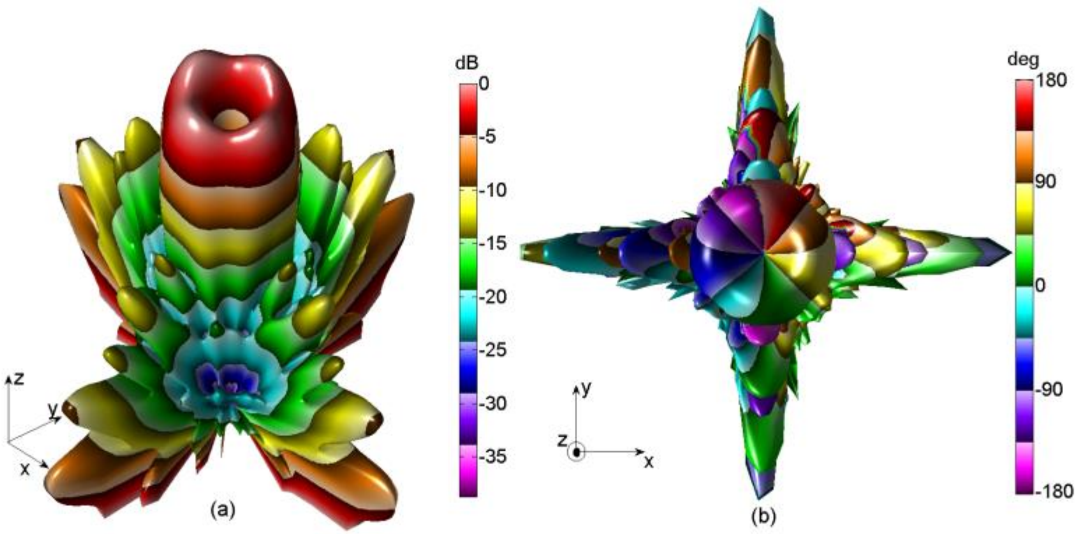




10x10 array factor

Array factor of a finite array with given phase distribution.

$$AF_{\theta,\varphi} = \sum_m \sum_n A_{mn}\, e^{-j(k\,x_m \sin\theta\cos\varphi + k\,y_n \sin\theta\sin\varphi + \psi(x_m, y_n))}$$

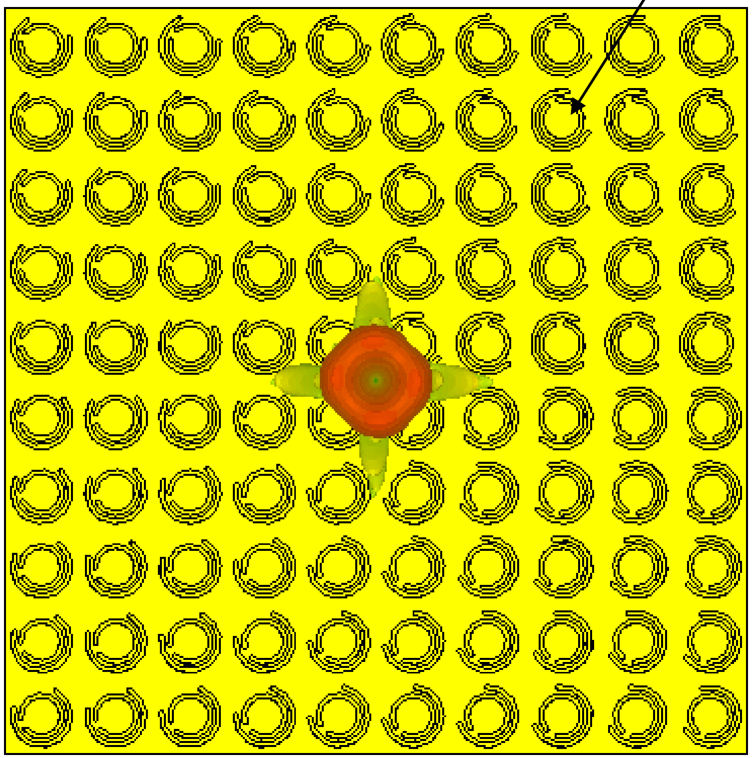


$$\psi(x,y) = \begin{cases} \tan^{-1}\dfrac{y}{x}, x > 0, y > 0 \\ \tan^{-1}\dfrac{y}{x} + \pi, x < 0 \\ \tan^{-1}\dfrac{y}{x} + 2\pi, x > 0, y \le 0 \end{cases}$$

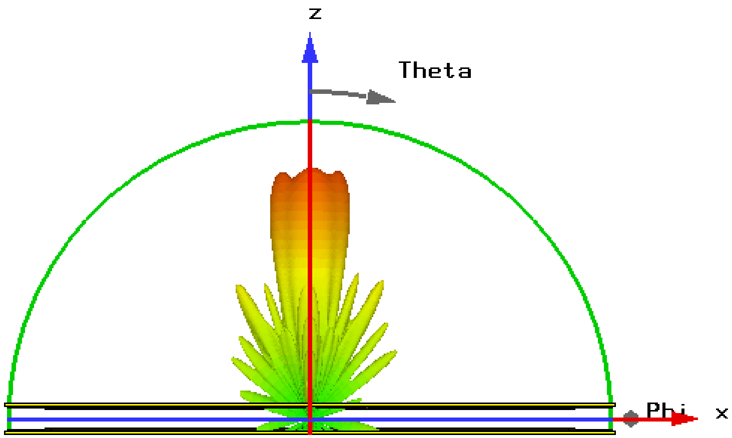
Predicted array factor of the 10x10 array with spiral phase distribution (a) amplitude, (b) phase.

10x10 array EM simulation

(x_m, y_n)

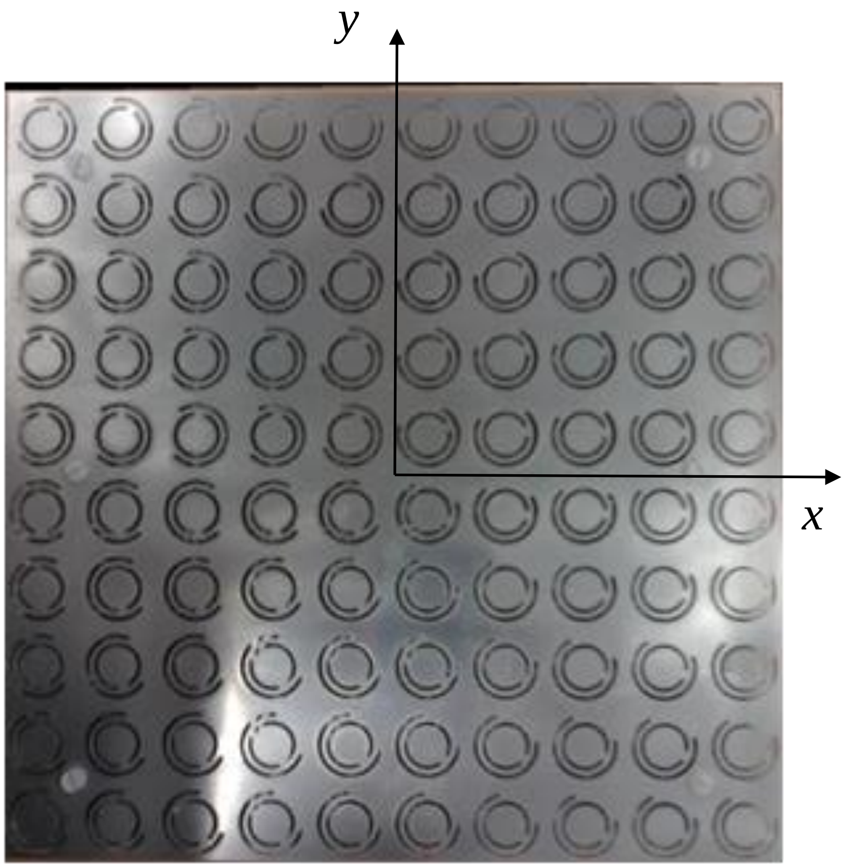


$$\psi(x,y)=\begin{cases}\tan^{-1}\dfrac{y}{x}, x>0, y>0\\ \tan^{-1}\dfrac{y}{x}+\pi, x<0\\ \tan^{-1}\dfrac{y}{x}+2\pi, x>0, y\le 0\end{cases}$$



Simulated 3D bi-static RCS of the 10x10 slit ring reflectarray with spiral phase distribution.

Manufactured sample

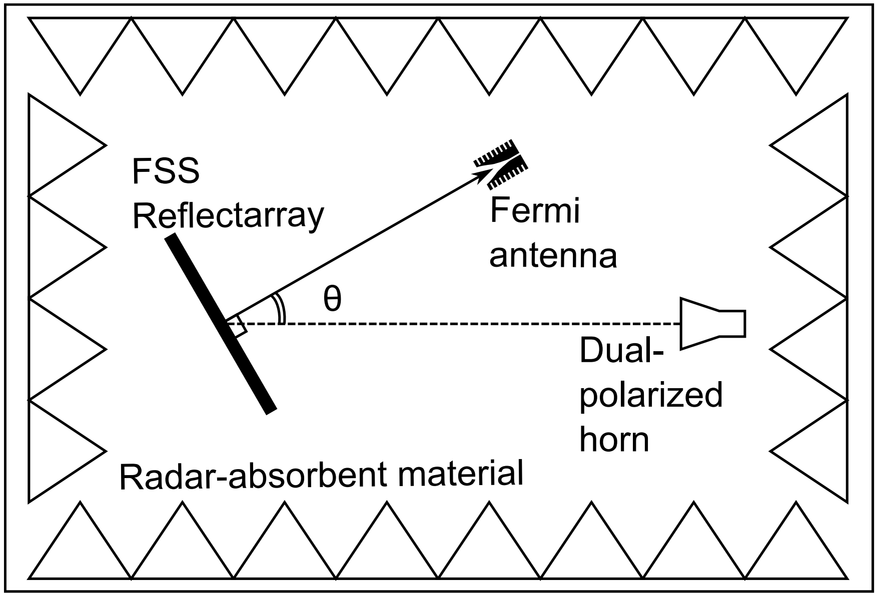


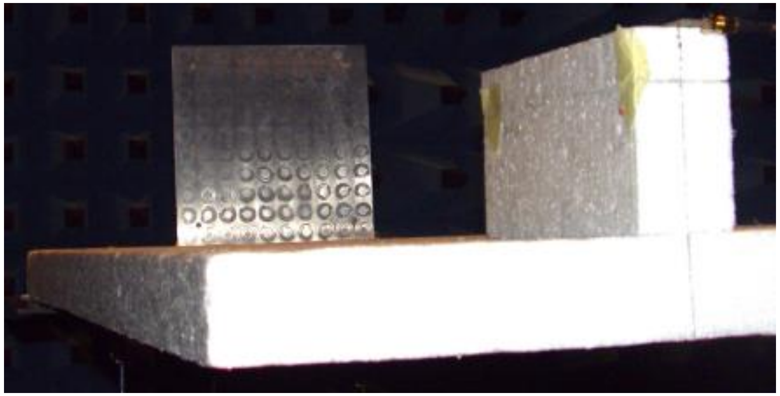
$$\psi(x,y)=\begin{cases}\tan^{-1}\dfrac{y}{x}, x>0, y>0\\ \tan^{-1}\dfrac{y}{x}+\pi, x<0\\ \tan^{-1}\dfrac{y}{x}+2\pi, x>0, y\le 0\end{cases}$$

The reflector has been milled from a 1mm thick aluminum with solid aluminum ground plane. The 7.5mm separation is maintained with plastic screws.

Measurement setup

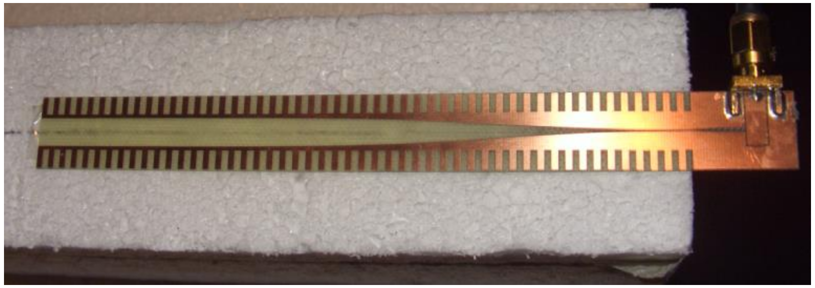
The setup consists of illuminating dual-polarized horn and rotating fixture with reflector and receiving Fermi antenna

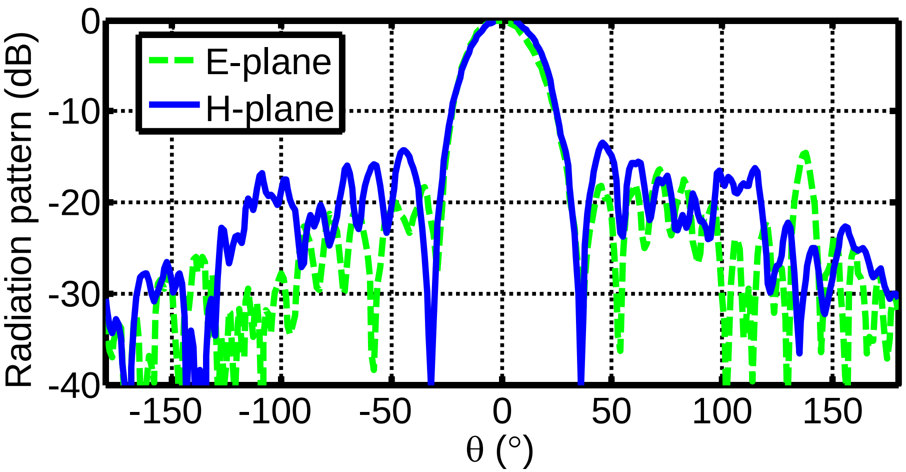




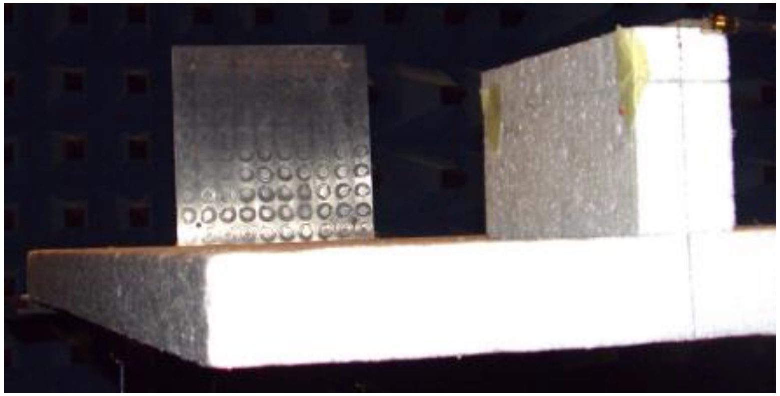
Rotating fixture with reflector and receiving Fermi antenna

Receiving fixture

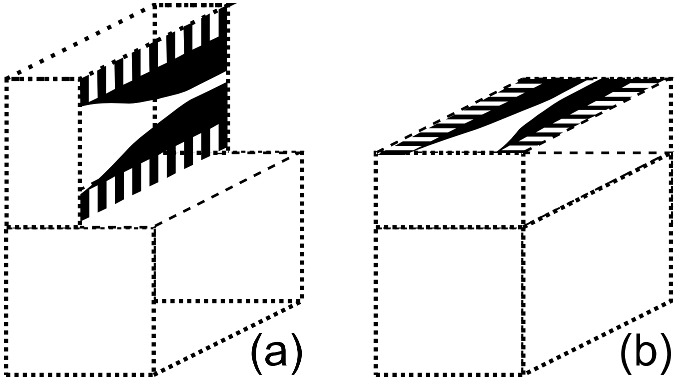




Fermi antenna and its radiation pattern in E- and H-plane

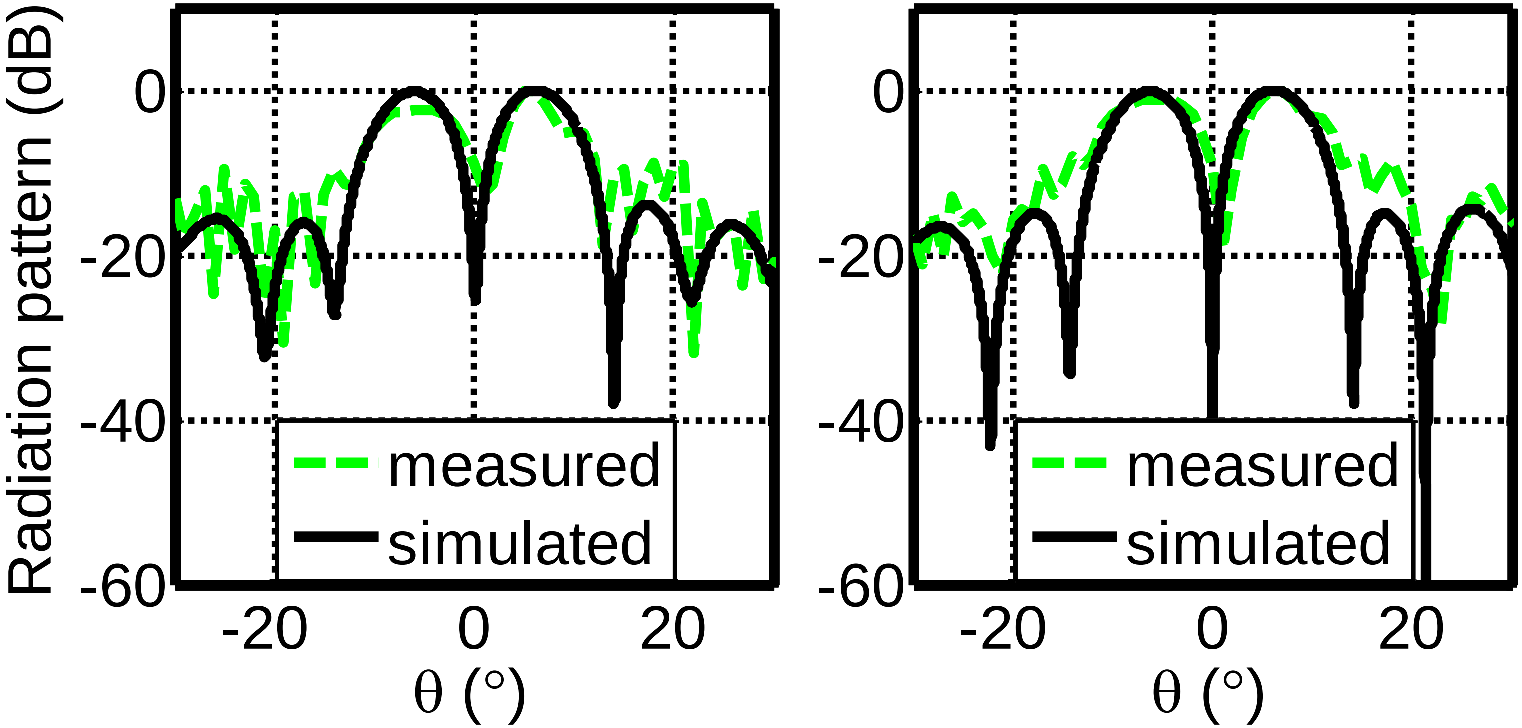


Rotating fixture with the reflector and Fermi antenna



Fermi antenna foam fixture

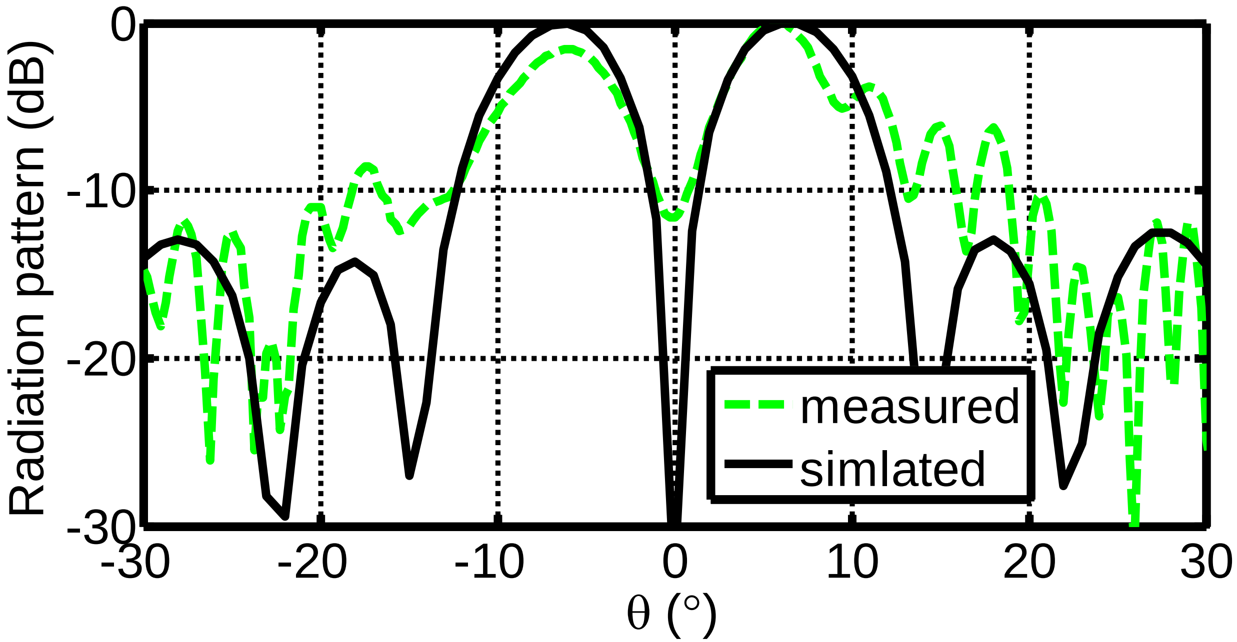
LP measurement result



Comparison of simulated and measured radiation patterns (normalised) when excited by a normally incident x-polarized plane wave at 10.4 GHz.

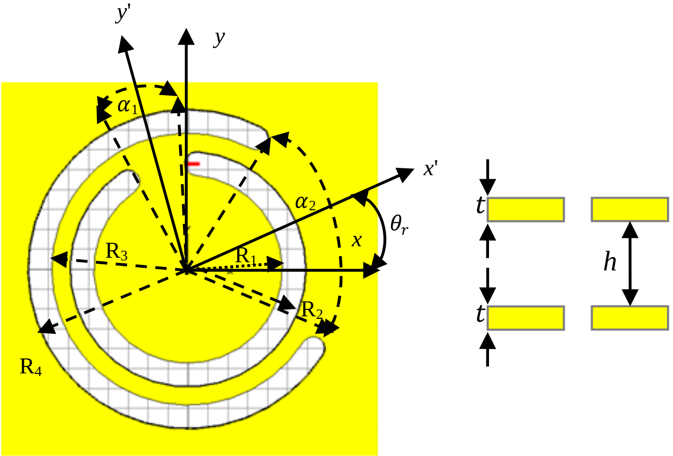
(*a*) E_θ for φ=0 and -90<θ<90 (*b*) E_θ for φ=90 and -90<θ<90

CP measurement results



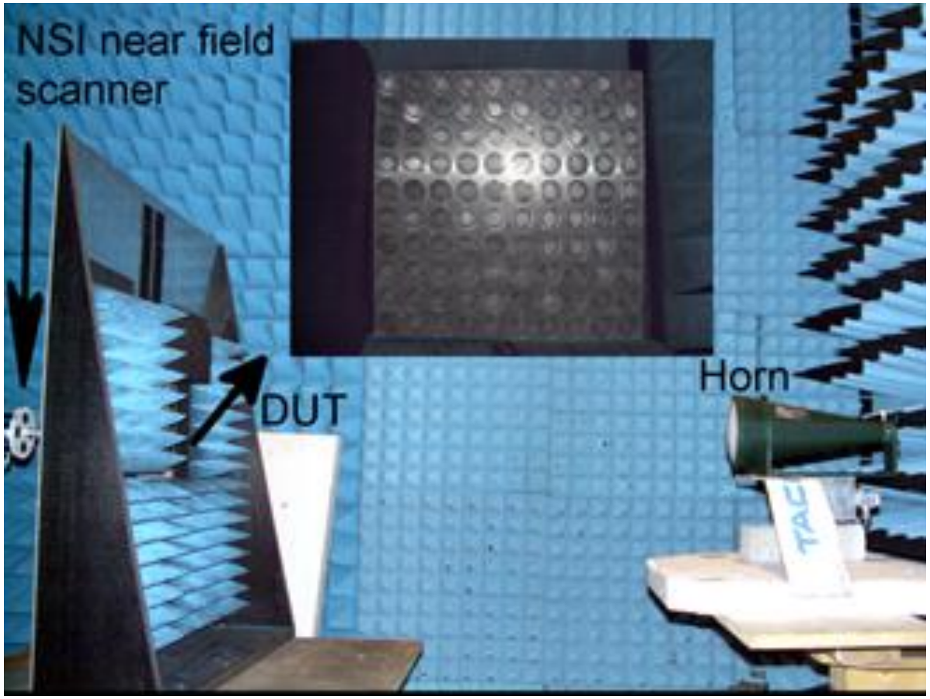
Comparison of simulated and measured radiation patterns (normalised) in plane φ=0 when excited by a normally incident CP-polarized plane wave at 10.4 GHz.

Transmit-array



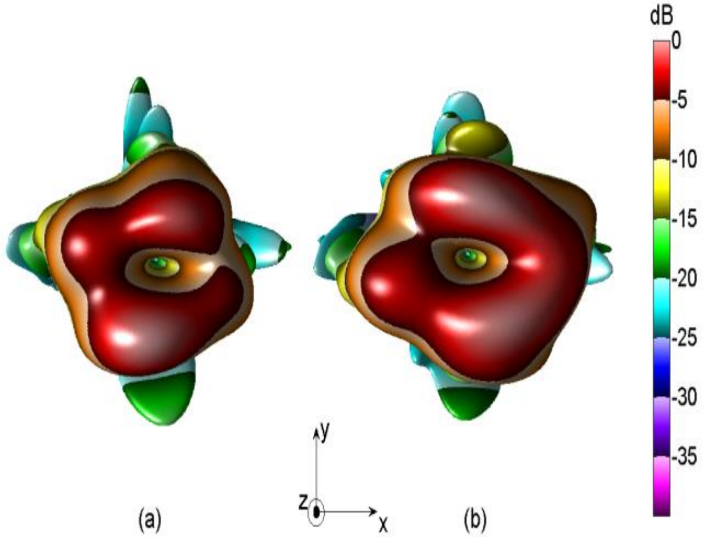
Unit cell

Measurement setup

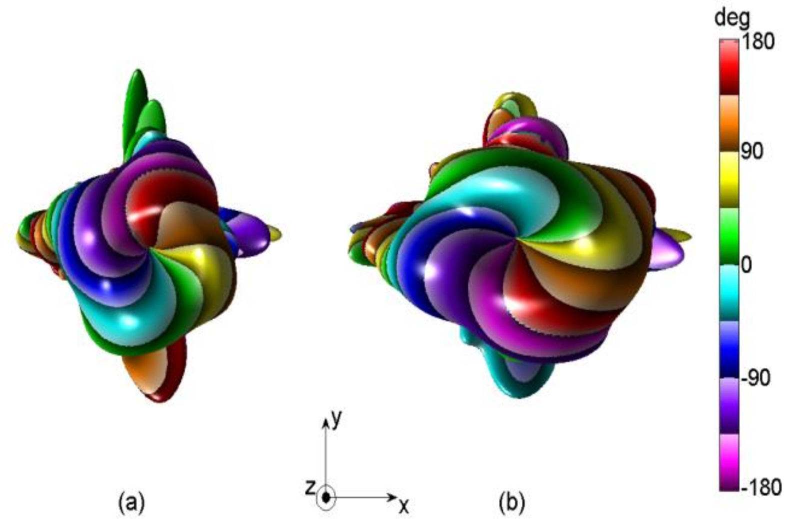


Measured radiation pattern

Magnitude

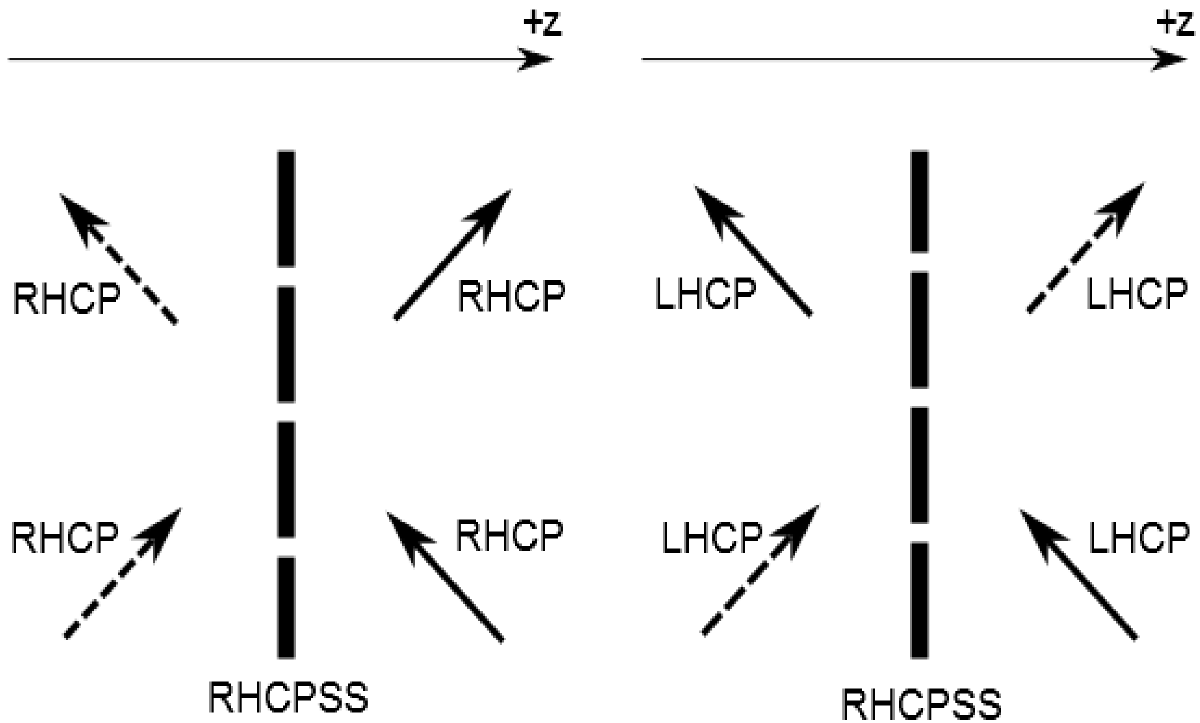


Phase



(a) RHCP, (b) LHCP excitation

Polarisation selectivity (CPSS)



(a) (b)

Reciprocal symmetrical right-hand circular polarisation selective surface: (a) – reflection, (b) – transmission.

Jones matrix formulation

General case: LP and CP Jones matrices

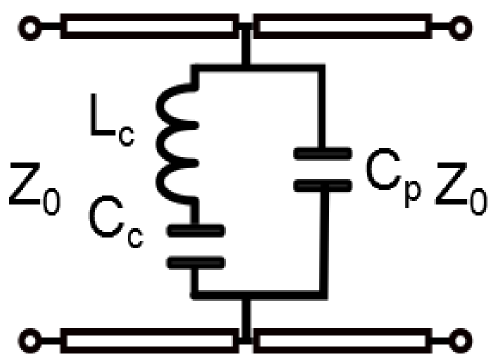
$$T_{lin}^{f} = \begin{pmatrix} S_{xx}^{21} & S_{xy}^{21} \\ S_{yx}^{21} & S_{yy}^{21} \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

$$T_{circ}^{f} = \frac{1}{2}\begin{pmatrix} A + D - j(B - C) & A - D + j(B + C) \\ A - D - j(B + C) & A + D + j(B - C) \end{pmatrix}$$

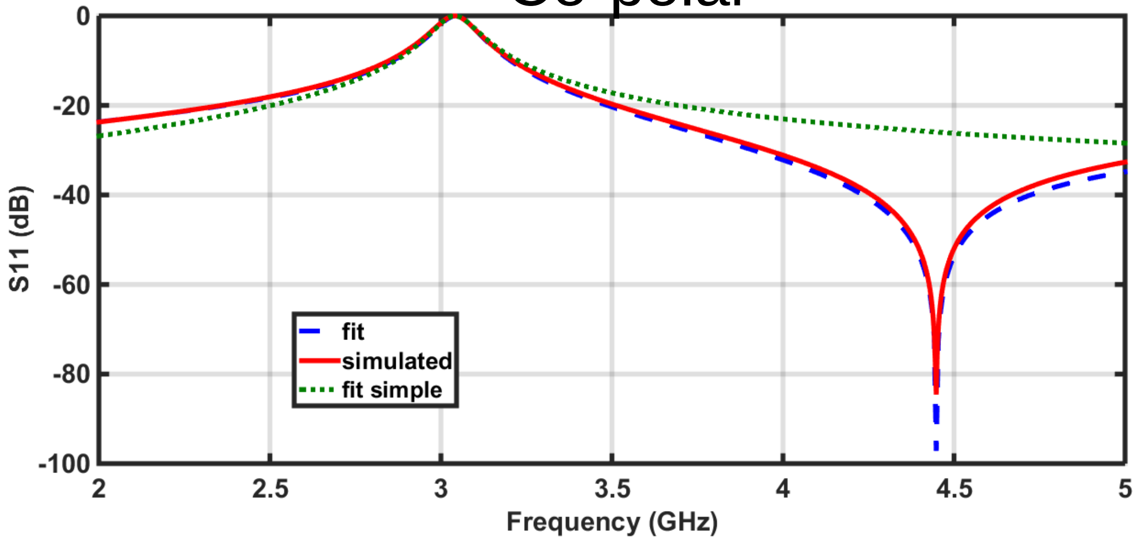
RHCPSS: LP and CP Jones matrices

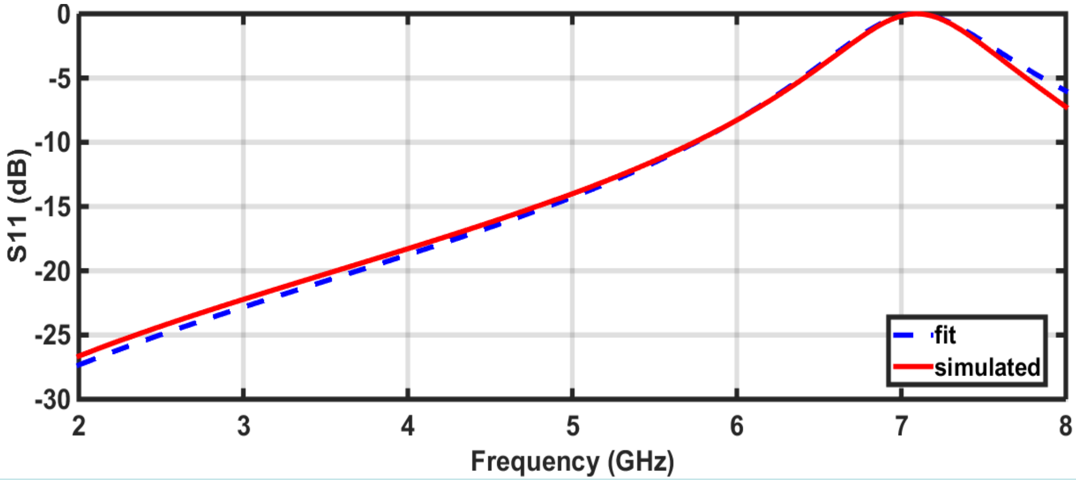
$$T_{circ}^{f} = \begin{pmatrix} 0 & 0 \\ 0 & S_{LCP,LCP}^{21} \end{pmatrix} \quad A = D = jB, B = -C$$

Single SRR model



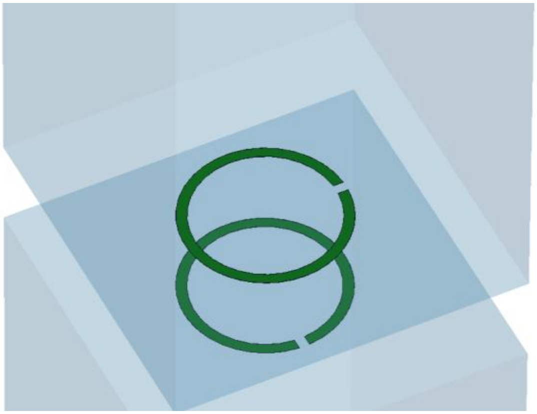
Co-polar



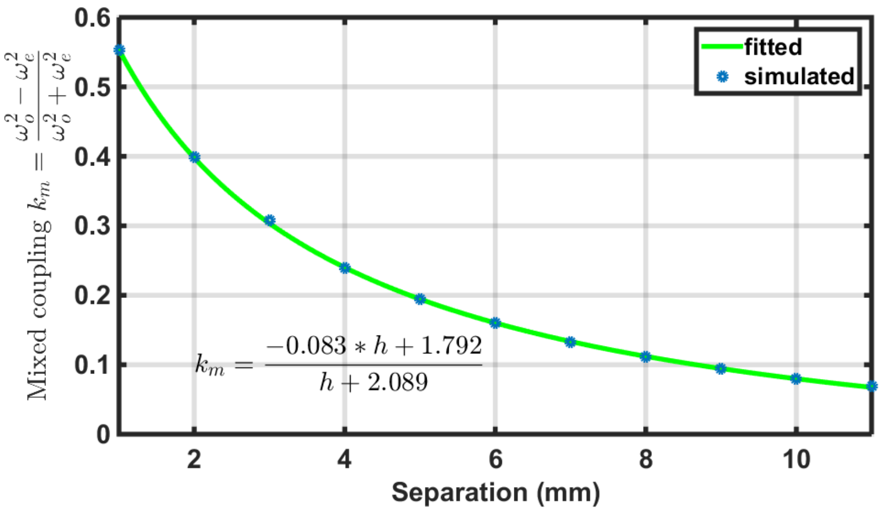


Cross-polar

SRRs magnetic coupling



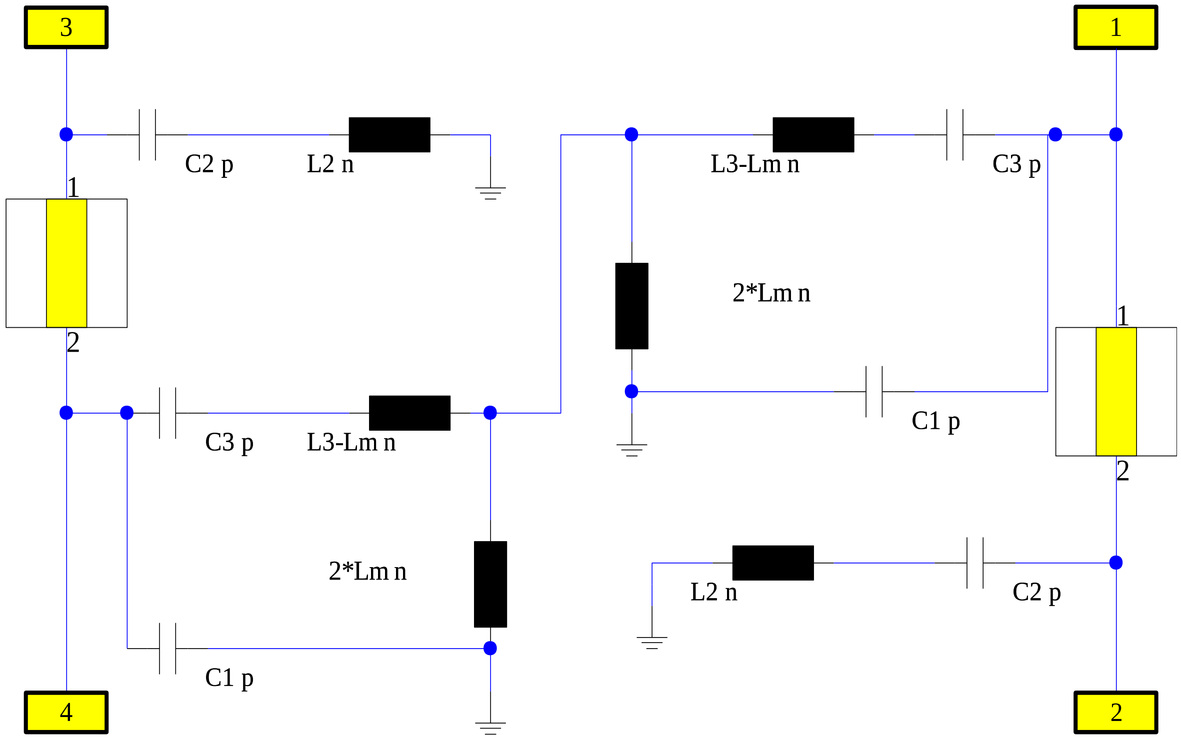
Twisted SRR
Unit cell



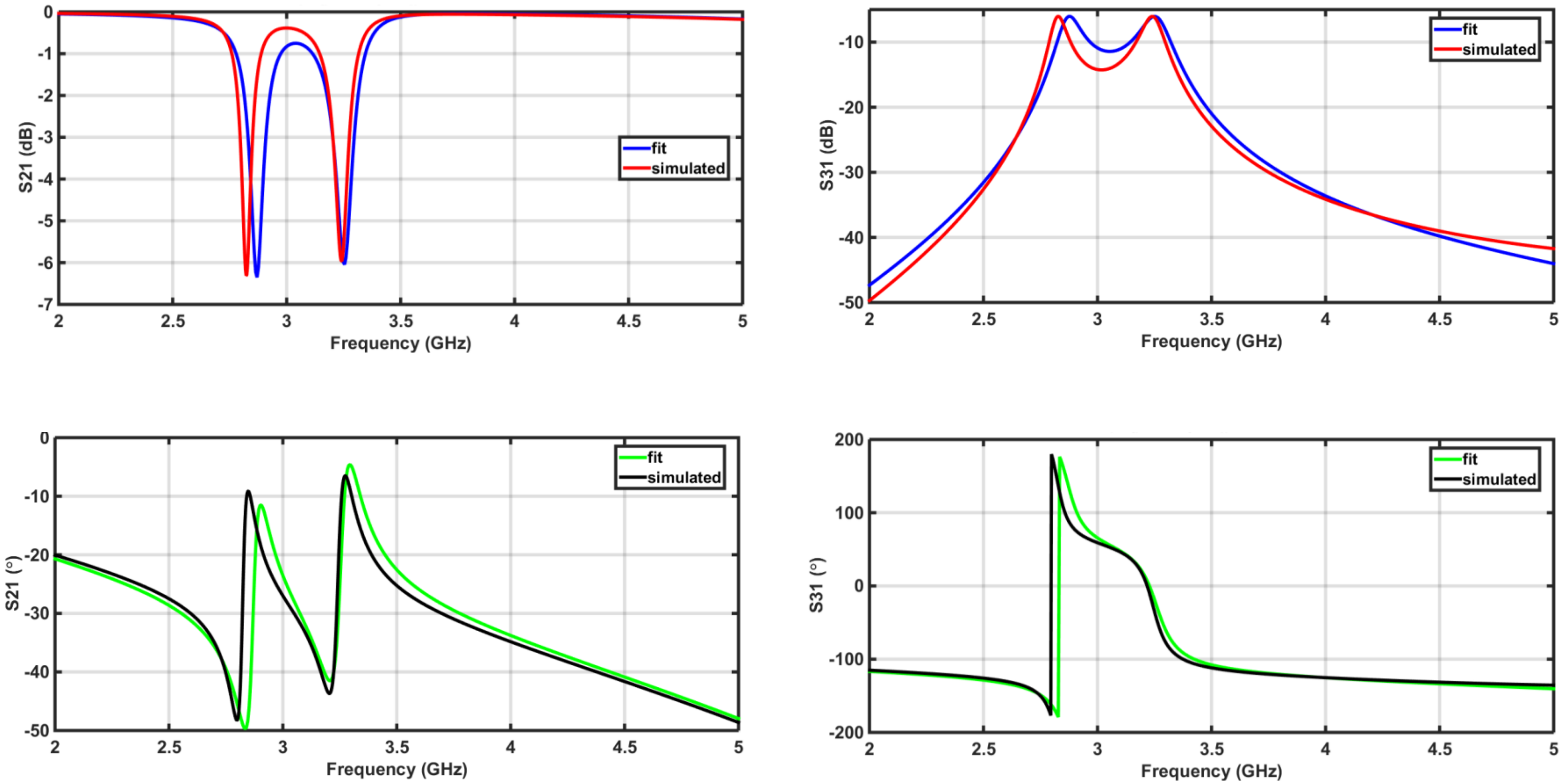
Coupling inductance

$$L_m = k_h L_3$$

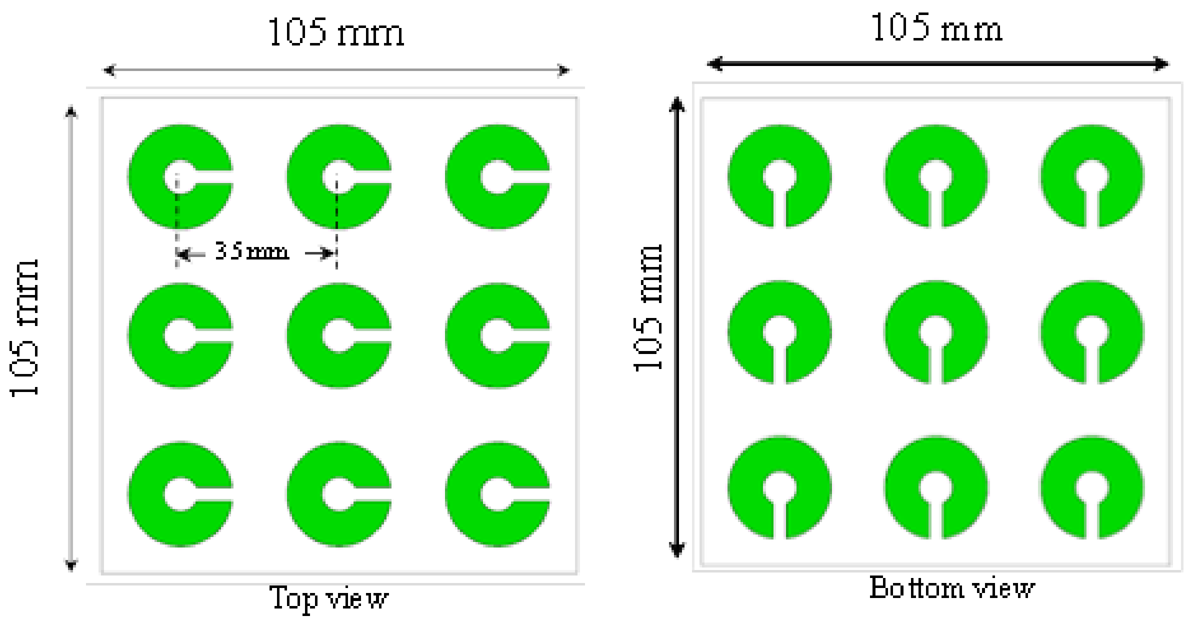
Equivalent circuit of 90 degree TSSR

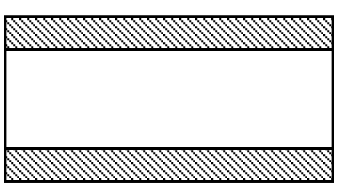


Fitted vs CST



RHCPSS


105 mm
105 mm
35mm
Top view
105 mm
105 mm
Bottom view


RO 4003C h3=0.5mm
Rohacell foam h2=5mm
RO 4003C, h1=0.5mm

Measurement RHCPSS